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RESEARCH MEMORANDUM

for the

Air Materiel Command, Army Air Forces

SIMULATED ALTITUDE INVESTIGATION OF STEWART-WARNER

MODEL 906-B COMBUSTION HEATER

By Frederick R. Ebersbach and Adolph J. Cervenka

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NATIONAL ADVISORY COMMITTEE
FOR AERONAUTICS

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NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

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SUMMARY

An investigation has been conducted to determine thermal and pressure-drop performance and the operational characteristics of a Stewart-Warner model 906-B combustion heater. The performance tests covered a range of ventilating-air flows from 500 to 3185 pounds per hour, combustion-air pressure drops from 5 to 35 inches of water, and pressure altitudes from sea level to 41,000 feet. The operational characteristics investigated were the combustion-air flows for sustained combustion and for consistent ignition covering fuel-air ratios ranging from 0.033 to 0.10 and pressure altitudes from sea level to 45,000 feet.

Rated heat output of 50,000 Btu per hour was obtained at pressure altitudes up to 27,000 feet for ventilating-air flows greater than 800 pounds per hour; rated output was not obtained at ventilating-air flow below 800 pounds per hour at any altitude.

The maximum heater efficiency was found to be 60.7 percent at a fuel-air ratio of 0.050, a sea-level pressure altitude, a ventilating-air temperature of 0° F, combustion-air temperature of 14° F, a ventilating-air flow of 690 pounds per hour, and a combustion-air flow of 72.7 pounds per hour.

The minimum combustion-air flow for sustained combustion at a pressure altitude of 25,000 feet was about 9 pounds per hour for fuel-air ratios between 0.037 and 0.099 and at a pressure altitude of 45,000 feet increased to 18 pounds per hour at a fuel-air ratio of 0.099 and 55 pounds per hour at a fuel-air ratio of 0.036. Combustion could be sustained at combustion-air flows above values of practical interest. The maximum flow was limited, however, by excessively high exhaust-gas temperature or high pressure drop.

Both maximum and minimum combustion-air flows for consistent ignition decrease with increasing pressure altitude and the two curves intersect at a pressure altitude of approximately 25,000 feet and a combustion-air flow of approximately 28 pounds per hour.

INTRODUCTION

As a part of the general program requested by the Air Materiel Command, Army Air Forces, to determine the performance and operational characteristics of aircraft combustion heaters, an investigation of a Stewart-Warner model 906-B combustion heater rated at 50,000 Btu per hour was conducted at the NACA Cleveland laboratory. The characteristics investigated were: thermal and pressure-drop performance at pressure altitudes from sea level to 41,000 feet; fuel-air ratio for best heater efficiency; minimum and maximum combustion-air flow for sustained combustion over a range of fuel-air ratios from 0.033 to 0.10 and pressure altitudes from sea level to 45,000 feet; and minimum and maximum combustion-air flow for consistent ignition at fuel-air ratios from 0.033 to 0.10 and pressure altitudes from sea level to 30,000 feet.

APPARATUS

The Stewart-Warner model 906-B combustion heater, the operation, and the test equipment are described in the following paragraphs:

Heater operation and altitude chamber. - A diagram of the Stewart-Warner model 906-B combustion heater, which is rated by the manufacturer at 50,000 Btu per hour at a combustion-air flow of 90 pounds per hour and a fuel pressure drop across solenoid valves and nozzles of 15 pounds per square inch, is presented in figure 1. The heater consists of a gasoline burner and a spirally arranged cross-flow plate-type heat exchanger. Combustion air enters the burner tangentially and mixes with fuel as it passes through the mixing cone. Fuel is injected into the burner through a spray nozzle and is ignited by means of a glow coil. At this point combustion takes place and the exhaust gases spiral through the heat exchanger and are exhausted normal to the longitudinal heater axis. The ventilating air flows parallel to the longitudinal heater axis. The burner and the heat exchanger are contained in a cylindrical jacket 7 inches in diameter and $17\frac{1}{2}$ inches long. Automatic controls for the heater are mounted on the heater jacket and include a combustion-air regulator (consisting of a bellows-operated butterfly valve, which maintains a constant flow of combustion air regardless of variations in the differences in pressure between the inlet and exhaust), and two fuel valves in series. Each fuel valve is

operated by a solenoid; one is used as a shut-off valve and the other is used to restrict the fuel flow to approximately 60 percent of the rated flow when low heater output is desired.

The setup used is shown schematically in figure 2. The heater was enclosed in a cylindrical altitude chamber 4 feet long and $2\frac{1}{2}$ feet in diameter in order to minimize heater leakage and all apparent leaks in the heater case were sealed.

Air supply and control. - Ventilating air, combustion air, and altitude-chamber cooling air were supplied by the refrigerated-air system of the laboratory and after passing through the setup were discharged into the altitude exhaust system.

Ventilating air was supplied and exhausted through 7-inch steel ducts with a suitable transition from an 8-inch supply duct. Combustion air was supplied through a 2-inch steel duct and the products of combustion were exhausted through a $2\frac{1}{2}$-inch stainless-steel duct. The altitude-chamber cooling air was supplied and exhausted through 2-inch ducts, which were insulated with 2 inches of hair felt. The ventilating-air-exit and combustion-air-exhaust ducts were insulated with 1/2 inch of asbestos and 2 inches of hair felt, and $1\frac{1}{2}$ inches of asbestos, respectively.

The pressure of the ventilating air and combustion air, the flow of the ventilating air, combustion air, and altitude-chamber cooling air, and the combustion-air pressure drop were controlled by valves upstream and downstream of the altitude chamber. The ventilating-air and combustion-air flows were measured with thin-plate orifices installed in accordance with A.S.M.E. specifications. The temperature of the refrigerated-air supply was controlled by electrical preheaters.

Fuel supply. - The fuel used was AN-F-28, Amendment-2; the flow was measured with a rotameter and was controlled by means of a needle valve. The fuel was cooled by passing it through a coil of 1/4-inch copper tubing located in the altitude-chamber cooling-air duct. Fuel pressure was obtained by pressurizing the fuel tank with nitrogen. Fuel temperatures were measured with single thermocouples both before and after the solenoid valves.

Power supply to the glow coil was varied with a slide-wire rheostat and measured with an ammeter and a voltmeter.

The air and exhaust-gas temperatures were measured by thermocouples located at stations upstream and downstream of the heater in

the ventilating-air and combustion-air ducts, as shown in figure 2. In the ventilating-air duct at the upstream station the installation consisted of a rake of three thermocouples and at the downstream station the installation consisted of two rakes of five thermocouples each. Combustion-air inlet and outlet (exhaust) temperatures were obtained with a single thermocouple at stations 1, 2, and 3 of figure 1. The thermocouples were unshielded iron constantan with the exception of the exhaust thermocouple, which was shielded chromel alumel. All thermocouples were connected individually through a selector switch to a self-balancing direct-reading potentiometer. The average reading for each rake was obtained by computation. A set of baffles was installed between the heater and the ventilating-air-outlet thermocouples to enable obtainment of a better value of the average outlet temperature.

The static pressure of the ventilating air upstream and downstream of the heater and of the combustion air upstream (station 1, fig. 1) and downstream (station 2) of the combustion-air regulator was obtained from piezometer rings of four taps each. The taps for each piezometer ring were circumferentially spaced 90°. The static pressure of the exhaust gases downstream of the heater (station 3) was obtained with a single pressure tap. The fuel pressure drop across solenoid valves and nozzles was measured as a differential pressure between a point directly upstream of the solenoid valves and a point in the combustion-air duct near the nozzle outlet.

PROCEDURE

Three groups of runs were conducted for ranges of altitude and fuel-air ratio to determine:

(a) Performance of the heater

(b) Minimum and maximum combustion-air flows for sustained combustion

(c) Minimum and maximum combustion-air flows for consistent ignition

Throughout the runs combustion- and ventilating-air temperatures were held as closely as possible to values requested by the Air Materiel Command. Although the ventilating-air temperatures were held near the desired values, it was impossible to control combustion-air temperatures accurately because of high relative heat gains and losses from the combustion-air ducts.

Performance Characteristics

The thermal and pressure-drop performance of the heater with controls was determined for pressure altitudes ranging from sea level to 41,000 feet. Ventilating-air flow was varied from 500 to 3185 pounds per hour and combustion-air pressure drop was varied from 5 to 35 inches of water. With controls removed, the fuel-air ratio for best heater efficiency and the thermal and pressure-drop performance at sea-level pressure altitude with this fuel-air ratio was determined.

The thermal and pressure-drop performance of the heater with automatic controls installed was obtained for a range of pressure altitudes with the ventilating-inlet-air temperature maintained at approximately 59° F and the combustion-air temperature at approximately 75° F. At each altitude the ventilating-air flow and the combustion-air pressure drop were varied to simulate the operating conditions affecting the heater when installed in an airplane in flight. These nominal conditions are as follows:

Pressure altitude (ft)	Ventilating-air flow (lb/hr)	Combustion-air pressure drop across regulator and heater (in. water)
Sea level	500	5
	700	5
	1100	15
	1800	25
	3185	35
11,000	500	5
	700	5
	1100	15
	1800	25
	2800	35
27,000	500	5
	1100	15
	1600	25
41,000	700	5
	1100	15

These runs were made with the restricting fuel solenoid open and closed and with the fuel-feed pressure 15 pounds per square inch above combustion-air static pressure.

After completion of these runs, the combustion-air regulator and the restricting solenoid valve in the fuel-supply duct were removed for the remainder of the program. The fuel-air ratio for best heater efficiency was determined at nominal operating conditions: sea-level pressure altitude; ventilating-air temperature, approximately 0° F; combustion-air temperature, approximately 12° F; and ventilating- and combustion-air flows of 690 and 72.7 pounds per hour, respectively. Thermal and pressure-drop performance of the heater were obtained with the fuel-air ratio for best heater efficiency and at the combustion- and ventilating-air conditions previously given with the exception of the ventilating-air flow, which was varied from about 500 to 1500 pounds per hour in six steps.

The isothermal ventilating-air pressure drop was obtained at sea-level inlet pressure and at a temperature of approximately 0° F for flows ranging from 500 to 1500 pounds per hour.

Combustion-Air Flow Limits for Sustained Combustion

Minimum combustion-air flows for sustained combustion were determined for pressure altitudes ranging from sea level to 45,000 feet for fuel-air ratios of 0.10, 0.066, 0.05, 0.04, and 0.036. The ventilating-air flow was kept constant at approximately 1100 pounds per hour and the ventilating-air temperature was kept constant at approximately -65° F. Combustion-air temperatures varied from 2° to -48° F and fuel temperature varied from 14° to -26° F.

The procedure followed for each set of conditions consisted in initially operating the heater at a normal flow and subsequently reducing combustion-air and fuel flows (maintaining a constant fuel-air ratio) until the temperature of the heater exhaust indicated that combustion had ceased. A value of combustion-air flow slightly higher than the point at which combustion ceased was considered the minimum flow limit. The heater was then reignited, the combustion-air and fuel flows were set at this slightly higher value, and complete performance data for these conditions were recorded.

The originally planned procedure for determining the maximum flows for sustained combustion was similar to that outlined in the preceding paragraph except that the combustion-air flow was to be increased to a value where burning ceased. The actual program was curtailed, however, in view of the results, which are described later.

Combustion-Air Flow Limits for Consistent Ignition

Runs to determine the combustion-air-flow limits for consistent ignition were made for a range of pressure altitudes up to 30,000 feet and for fuel-air ratios ranging from 0.10 to 0.033. Ventilating-air flow was held at 1100 pounds per hour and temperature at approximately -65° F. The combustion-air-inlet temperatures ranged from -71° to -29° F. The fuel temperature varied from -70° to -28° F. The voltage across the ignitor was kept at 28.5 volts.

In order to determine a combustion-air-flow limit for consistent ignition, the heater was operated normally to burn up fuel from the previous run, the fuel flow was set by the needle valve at the required fuel-air ratio, and then the fuel was shut off by the solenoid valve. The combustion-air flow was then set at a particular test value and the ignitor and fuel simultaneously turned on for at least 1 minute. If ignition occurred, as indicated by a progressive rise in the exhaust temperature, the fuel and ignitor were turned off and the accumulated fuel in the heater allowed to burn out. After all the fuel had been burned and the heater-exhaust temperature had dropped to below 0° F, a second attempt at ignition was made. After the third attempt the combustion-air flow was changed. In the event that ignition did not occur in the initial attempt, the conditions were so changed that ignition would occur and allow the accumulated fuel to burn out. The original conditions would then be reset and another start attempted. Three attempts were made even though ignition did not occur on the first attempt.

After three successful attempts at starting were made for each fuel-air ratio at a constant rate of combustion-air flow, the pressure altitude or the combustion-air flow was changed and the runs repeated until the minimum and maximum flows were obtained.

Further runs were made to determine the effect on ignition of energizing the ignitor before fuel was admitted to the heater. The runs were made at a pressure altitude of 25,000 feet, combustion-air temperature of -65° F, combustion-air flow of 30 pounds per hour, and fuel-air ratios of 0.10 and 0.066. The procedure followed was similar to the other ignition runs with the exception that the ignitor was energized about 30 seconds before the fuel solenoid was opened. This period was the time required for the current input to the ignitor to reach a minimum, which indicated that the ignitor coil had reached its equilibrium temperature.

The heater output was calculated from the temperature increase and weight flow of the ventilating air and a specific-heat value of

0.24 Btu per pound per $^{\circ}$F. The heater efficiency was calculated by dividing the heater output by the heat content of the fuel. A lower heating value of 18,500 Btu per pound and a higher heating value of 20,000 Btu per pound were used when the exhaust-gas temperature was more or less than 212° F, respectively.

RESULTS AND DISCUSSION

Performance Characteristics

The important data indicating the altitude-performance characteristics of the combustion heater are given in table I and in figures 3 to 5.

Heater with automatic controls. - The heater performance for unrestricted and restricted fuel flow and for combustion-air and ventilating-air pressure altitudes of sea level and 10,000 feet is shown in figure 3. The heat output is plotted against ventilating-air flow; the corresponding values of the combustion air-pressure drop (across regulator and heater), which was set prior to the run, and the resulting combustion-air flow are included. The heat output increases with increasing ventilating-air or fuel flow. As the pressure drop across the combustion chamber and regulator is increased from 5 to 15 inches of water, the combustion-air flow shows a general but erratic increase; however, for pressure drops from 15 to 35 inches of water, the regulator holds a nearly constant flow. These erratic trends may be due to friction in the moving parts of the regulator. Static-pressure drop of the combustion air through the regulator and combustion chamber as given in both figure 3 and table I is uncorrected for difference in cross-sectional area of flow section. A rated heat output of 50,000 Btu per hour was obtained at pressure altitude up to 27,000 feet for ventilating-air flows greater than 800 pounds per hour; rated output was not obtained at ventilating-air flows below 800 pounds per hour at any altitude (table I).

The effect of pressure altitude on the heater performance is shown in figure 4 for ventilating-air flows of 500 and 1100 pounds per hour and for combustion-air pressure drops of 5.0 and 15.0 inches of water. The rate of heat output is practically unaffected by pressure altitude for constant ventilating-air and fuel flows. Combustion-air pressure drop through the combustion chamber increases and combustion-air flow and exhaust temperature decrease with increasing pressure altitude.

The pressure drop of the ventilating air obtained during the performance and additional isothermal runs is shown in figure 5. Data for

isothermal pressure drop are included in table II. The values of pressure drop $\sigma_i \Delta P$ have been corrected to standard sea-level-altitude density and are plotted against the ventilating-air flow for various values of outlet-to-inlet density ratio σ_o/σ_i.

Heater with automatic controls removed. - The effect of fuel-air ratio on heat output, heater efficiency, and ventilating- and combustion-air pressure drop with controls removed is given in figure 6 and table II. A maximum heater efficiency of 60.7 percent was obtained at a fuel-air ratio of 0.05 for ventilating- and combustion-air flows of 690 and 72.7 pounds per hour, respectively. Ventilating- and combustion-air pressure drop increase slightly with increasing values of fuel-air ratio because of increasing momentum pressure drop.

Heat output, heater efficiency, ventilating- and combustion-air pressure drop at the fuel-air ratio for maximum efficiency (0.05) over a range of ventilating-air flow is presented in figure 7 and in table II. The heat output as indicated by this figure is lower than that obtained in normal operation because of the smaller fuel and combustion-air flows used during the investigation (3.6 and 72.7 lb/hr, respectively) than those at which the heater is rated (4.7 and 90 lb/hr, respectively).

Combustion-Air Flow Limits for Sustained Combustion

All the important data obtained in investigating the combustion-air flow limits for sustained combustion at small and large combustion-air flows are presented in tables III and IV, respectively.

For pressure altitudes of sea level and 10,000 feet, combustion was sustained at combustion-air flows as low as 13 percent of the manufacturer's rating of 90 pounds per hour. The minimum limits were not determined because the apparatus did not permit accurate measurement of the small flows at the existing air densities and modification of the equipment was not warranted because the flows are much smaller than values of practical interest. For pressure altitudes of about 20,000 feet, measurable flows were obtained at which combustion ceased. The minimum flow for sustained combustion at a pressure altitude of 25,000 feet was approximately 9 pounds per hour for fuel-air ratios between 0.037 and 0.099; at a pressure altitude of 45,000 feet the combustion-air flow limits for sustained combustion varied considerably with fuel-air ratio. At a fuel-air ratio of 0.10 the limit was 18 pounds per hour and at a fuel-air ratio of 0.036 the limit increased to 55 pounds per hour. At altitudes below 40,000 feet, fuel-air ratio had little effect on the minimum limit.

The range of combustion-air flows and pressure altitudes over which the heater was operated in attempts to determine the maximum combustion-air flow limits for sustained combustion is presented in table IV. Combustion could be sustained at combustion-air flows above values of practical interest. The determination of the maximum flow for sustained combustion, however, was limited by other operational considerations. At high fuel-air ratios combustion-air flow was so limited by excessively high exhaust-gas temperatures that maximum combustion-air flows for sustained combustion could not be determined. For example, at a fuel-air ratio of 0.064, a combustion-air flow of 177 pounds per hour (about twice rated flow) produced an exhaust-gas temperature of about 1805° F. At lower values of fuel-air ratio, the determination of maximum combustion-air flow was prohibited by excessive pressure drop. For example, at a fuel-air ratio of 0.034 and a combustion-air flow of 388 pounds per hour (more than four times the rated flow) the pressure drop was 138.7 inches of water. A maximum sustained combustion limit was obtained at a fuel-air ratio of 0.026 and a combustion-air flow of 514 pounds per hour; the resulting pressure drop was 196 inches of water.

Combustion-Air Flow Limits for Consistent Ignition

The combustion-air flows for consistent ignition obtained at various fuel-air ratios and pressure altitudes are presented in figure 8 and table V. At sea-level pressure altitude, the maximum combustion-air flow for consistent ignition was 280 pounds per hour at a fuel-air ratio of 0.05. A minimum limit of 50 pounds per hour was obtained at a fuel-air ratio of 0.10. Both maximum and minimum combustion-air flows for consistent ignition decreased with increasing pressure altitude, the maximum limit decreasing more rapidly. The two limit curves intersected at a pressure altitude of approximately 25,000 feet and a combustion-air flow of 28 pounds per hour.

The runs to determine the effect on ignition of heating the ignitor to its equilibrium temperature prior to the injection of fuel into the combustion chamber indicated that there was no improvement over the ignition time obtained with the standard ignition procedure at the same conditions.

SUMMARY OF RESULTS

The investigation conducted on the Stewart-Warner model 906-B aircraft combustion heater gives the following results:

1. A rated heat output of 50,000 Btu per hour was obtained at pressure altitudes up to 27,000 feet for ventilating-air flows greater than 800 pounds per hour; rated output was not obtained at ventilating-air flows below 800 pounds per hour at any altitude.

2. Maximum heater efficiency of 60.7 percent was obtained at a fuel-air ratio of 0.050, sea-level pressure altitude, ventilating-air temperature of 0° F, combustion-air temperature of 14° F, ventilating-air flow of 690 pounds per hour, and combustion-air flow of 72.7 pounds per hour.

3. The minimum rate of combustion-air flow for sustained combustion at a pressure altitude of 25,000 feet was about 9 pounds per hour for fuel-air ratios between 0.037 and 0.099 and at a pressure altitude of 45,000 feet increased to 18 pounds per hour at a fuel-air ratio of 0.10 and to 55 pounds per hour at a fuel-air ratio of 0.036. Combustion could be sustained at combustion-air flow rates above values of practical interest. The maximum flow was limited, however, by excessively high exhaust-gas temperature or high pressure drop.

4. Both maximum and minimum combustion-air flows for consistent ignition decreased with increasing pressure altitude and became equal at a pressure altitude of approximately 25,000 feet and a combustion-air flow of approximately 28 pounds per hour.

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TABLE I - HEATER PERFORMANCE WITH AUTOMATIC CONTROLS INSTALLED

Nominal pressure altitude (ft)	Inlet pressure (in. Hg abs.)	Ventilating air: Flow (lb/hr)	Ventilating air: Inlet temperature (°F)	Ventilating air: Outlet temperature (°F)	Ventilating air: Temperature rise (°F)	Ventilating air: Enthalpy change (Btu/hr)	Ventilating air: Pressure drop (in. water)	Combustion air: Total static-pressure drop (in. water)	Combustion air: Pressure drop through combustion-air regulator (in. water)	Combustion air: Pressure drop through combustion chamber (in. water)
Sea level	29.27	500	59	400	341	41,100	1.6	5.2	2.2	3.0
	29.37	682	60	354	294	48,300	2.7	5.0	2.0	3.0
	29.60	1030	60	262	202	50,000	4.8	14.8	9.0	5.8
	29.20	1800	58	185	127	54,850	11.7	25.0	19.5	5.5
	29.40	3150	60	136	76	57,400	32.8	34.0	27.3	6.7
	29.57	485	59	310	251	29,350	1.3	4.9	2.1	2.8
	28.97	710	58	280	222	38,000	2.6	4.8	2.0	2.8
	29.10	1050	60	192	132	36,300	4.6	15.0	9.1	5.9
	29.20	1810	59	151	92	40,000	11.0	25.7	20.0	5.7
	29.20	3185	60	116	56	42,800	32.2	34.0	27.8	6.2
11,000	19.97	500	61	404	343	41,300	2.5	5.0	2.7	2.3
	19.97	680	57	356	299	49,000	3.9	5.0	2.4	2.6
	19.91	1075	59	316	257	51,100	7.5	14.8	7.2	7.6
	20.00	1850	60	185	125	55,500	20.5	26.0	10.4	15.6
	20.00	2730	59	156	93	61,000	39.4	35.1	28.4	6.7
	20.07	510	61	362	301	37,100	2.4	5.0	2.8	2.2
	20.07	675	59	316	257	41,800	3.6	5.0	2.5	2.5
	19.97	1105	59	262	203	38,200	7.0	14.7	6.7	8.0
	19.90	1860	60	151	91	40,600	19.0	26.0	10.2	15.8
	20.10	2800	60	124	64	43,000	39.0	35.5	28.8	6.7
27,000	9.86	1150	59	238	179	49,600	17.9	14.8	3.9	10.9
	9.97	530	58	322	264	33,700	4.8	4.8	1.7	3.1
	9.96	1150	59	193	134	37,100	16.1	13.8	2.5	11.3
	9.95	1570	99	223	124	46,900	23.0	26.5	19.9	6.6
41,000	4.96	695	100	--------	--------	--------	10.2	5.0	--------	--------
	4.96	695	100	--------	--------	--------	10.2	5.0	--------	--------
	5.06	1160	59	--------	--------	--------	34.5	15.5	--------	--------

Nominal pressure altitude (ft)	Combustion air: Flow (lb/hr)	Combustion air: Inlet temperature (°F)	Fuel: Flow (lb/hr)	Fuel: Temperature (°F)	Fuel: Heating value (Btu/hr)	Fuel: Feed pressure (lb/sq in.)	Heater efficiency (percent)	Fuel-air ratio	Exhaust temperature (°F)	Restricting solenoid valve position	η_{comb}	Combustion temp °F
Sea level	76.6	78	4.47	120	82,700	14.93	49.7	0.0583	1080			
	72.1	78	4.47	113	82,700	14.64	58.4	.0620	980			
	108.0	63	5.10	99	94,350	14.74	53.0	.0472	980	Open	86.5	257
	105.0	68	4.64	90	85,850	15.72	64.0	.0442	930		97.2	273
	111.0	67	4.53	87	83,800	14.93	68.5	.0408	726		96.3	254
	75.8	74	3.28	102	60,700	15.80	48.4	.0433	872			
	72.2	74	3.23	106	59,750	14.58	63.6	.0447	670			
	109.0	62	3.59	96	66,400	14.74	54.6	.0326	755	Closed		
	105.0	68	3.29	84	60,850	14.84	65.5	.0313	652			
	110.8	67	3.29	81	60,850	14.98	70.4	.0297	572			
11,000	62.0	81	4.70	117	87,000	15.27	47.5	0.0758	1015			
	62.0	79	4.81	113	89,000	14.93	55.0	.0776	1043			
	87.0	69	5.05	88	93,400	15.52	54.7	.0580	955	Open		
	88.0	68	4.53	88	83,800	15.32	66.2	.0515	820			
	89.0	89	4.64	85	85,800	15.42	71.1	.0522	770			
	62.5	80	3.27	113	60,500	14.98	61.3	.0523	900			
	63.0	79	3.27	109	60,500	14.98	69.1	.0519	840			
	89.0	68	3.55	82	65,700	14.78	58.2	.0399	755	Closed		
	87.0	67	3.29	80	60,850	14.98	66.7	.0378	667			
	90.0	66	3.34	79	61,800	15.03	69.6	.0371	618			
27,000	60.0	70	4.86	95	90,000	15.03	55.1	0.0810	900	Open		
	40.0	80	3.08	105	57,000	14.93	59.1	.0770	680	Closed		
	61.0	71	3.24	91	60,000	14.58	61.8	.0531	755			
	56.0	103	4.66	124	86,200	15.23	57.6	.0832	795	Open		
41,000	33.0	88	--------	--------	--------	--------	--------	--------	--------	--------		
	33.0	80	--------	--------	--------	--------	--------	--------	--------	--------		
	42.5	74	--------	--------	--------	--------	--------	--------	--------	--------		

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TABLE II - HEATER PERFORMANCE WITHOUT AUTOMATIC CONTROLS INSTALLED

[Nominal pressure altitude, sea level]

Variable	Inlet pressure (in. Hg abs.)	Ventilating air						Combustion air	
		Flow (lb/hr)	Inlet temperature (°F)	Outlet temperature (°F)	Temperature rise (°F)	Enthalpy change (Btu/hr)	Pressure drop (in. water)	Flow (lb/hr)	Inlet temperature (°F)
Ventilating-air flow	29.96	1515	0		Isothermal		5.3	-------	-------
	29.96	1300	0		Isothermal		4.0	-------	-------
	29.86	1070	0		Isothermal		2.8	-------	-------
	29.86	708	1		Isothermal		1.3	-------	-------
	29.86	528	2		Isothermal		.7	-------	-------
	29.91	510	1	294	293	36,000	1.3	71.6	13
	29.91	1135	-2	164	166	45,400	4.6	71.4	12
	30.01	1530	-2	121	123	45,350	---	72.0	11
	29.96	1295	0	142	142	44,300	5.8	71.6	12
	29.96	887	0	197	197	42,100	3.1	71.7	13
Fuel flow	29.96	688	-6	134	140	23,200	1.8	72.0	7
	29.96	688	-1	180	181	30,000	2.0	72.0	11
	29.86	690	0	243	243	40,400	2.2	72.7	14
	29.86	693	0	299	299	49,900	2.5	72.0	15
	29.86	688	0	313	313	51,900	2.6	71.7	16
	29.81	683	0	269	269	44,300	2.2	71.5	13
	29.76	670	2	278	276	44,600	2.2	71.6	14

Variable	Combustion-air pressure drop (in. water)	Fuel			Heater efficiency (percent)	Fuel-air ratio	Exhaust-gas temperature (°F)
		Flow (lb/hr)	Temperature (°F)	Heating value (Btu/hr)			
Ventilating-air flow	-------	-------	-------	-------	-------	-------	-------
	-------	-------	-------	-------	-------	-------	-------
	-------	-------	-------	-------	-------	-------	-------
	-------	-------	-------	-------	-------	-------	-------
	-------	-------	-------	-------	-------	-------	-------
	2.3	3.55	27	65,650	54.8	0.0496	850
	2.2	3.56	22	65,850	69.0	.0498	700
	2.2	3.55	20	65,650	69.0	.0493	645
	2.1	3.56	23	65,850	67.3	.0497	665
	2.2	3.57	24	66,050	63.8	.0498	755
Fuel flow	2.0	2.37	24	43,850	52.9	0.0329	530
	2.1	2.81	28	52,000	57.7	.0390	660
	2.3	3.60	29	66,600	60.7	.0495	810
	2.3	4.76	30	88,100	56.7	.0661	955
	2.7	6.20	28	114,700	45.2	.0865	1010
	2.3	4.01	27	74,200	59.7	.0561	850
	2.3	4.01	27	74,200	60.0	.0560	885

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TABLE III - HEATER PERFORMANCE

Nominal pressure altitude (ft)	Inlet pressure (in. Hg abs.)	Ventilating air						Combustion air	
		Flow (lb/hr)	Inlet temperature (°F)	Outlet temperature (°F)	Temperature rise (°F)	Enthalpy change (Btu/hr)	Pressure drop (in. water)	Inlet pressure (in. Hg abs.)	Flow (lb/hr)
Sea level	29.8	1120	-67	2	69	18,550	--------	29.8	14.8
	29.8	1095	-68	- 6	62	16,300	--------	29.8	14.6
	29.8	1105	-69	-20	49	13,000	--------	29.8	14.9
	29.8	1110	-69	-26	43	11,000	--------	29.8	14.5
	29.8	1120	-69	-37	32	8,600	--------	29.8	14.6
10,000	20.7	1160	-60	- 2	58	16,150	4.9	20.7	12.0
	20.6	1180	-65	- 9	56	15,860	5.0	20.6	11.8
	20.6	1170	-66	-20	46	12,920	4.8	20.6	11.5
	20.6	1165	-59	-22	37	10,340	4.6	20.6	11.8
	20.5	1170	-58	-34	24	6,740	4.6	20.5	11.8
20,000	13.6	1100	-51	-17	34	8,980	6.7	13.6	9.3
	12.9	1090	-57	-35	22	5,760	6.2	12.9	10.8
	13.1	1085	-59	-12	37	9,640	6.4	13.1	10.9
	12.8	1095	-60	-14	46	12,100	7.7	12.8	10.3
	13.8	1060	-62	-21	41	10,430	6.4	13.8	11.5
25,000	10.9	1030	-62	-20	42	10,380	7.2	10.9	8.6
	10.9	1030	-61	-22	39	9,640	7.2	10.9	8.5
	10.7	1035	-60	-40	20	4,970	7.1	10.7	9.2
	10.6	1035	-60	-44	16	3,970	6.8	10.6	9.8
	11.3	1033	-62	-44	18	4,470	6.2	11.3	8.8
30,000	8.8	1065	-64	-20	44	11,250	8.7	8.8	10.1
	8.8	1070	-61	-25	36	9,240	9.0	8.8	11.0
	8.8	1065	-60	-27	33	8,430	8.9	8.8	10.9
	8.7	1065	-60	-29	31	7,920	8.6	8.7	10.8
	8.8	1065	-60	-31	29	7,420	8.7	8.8	10.9
35,000	6.8	1010	-68	-21	47	11,400	14.3	6.8	17.5
	6.8	1080	-68	-47	21	5,440	15.4	6.8	17.3
	6.8	1130	-69	-46	23	6,240	14.8	6.8	17.2
	6.8	1085	-70	-47	23	5,990	15.3	6.8	17.4
	6.7	1095	-71	-49	22	5,780	15.8	6.7	17.3
40,000	5.2	825	-67	- 7	60	11,880	12.2	5.2	16.7
	5.2	835	-67	-11	56	11,220	11.9	5.2	16.8
	5.0	915	-72	-47	25	5,460	14.0	5.0	17.8
	5.1	915	-73	-23	50	10,920	14.9	5.1	20.5
	5.3	940	-67	42	109	24,530	16.2	5.3	40.5
45,000	6.0	1075	-66	- 7	59	15,220	21.0	4.2	18.2
	6.2	1175	-66	-48	18	5,075	19.6	4.1	18.2
	6.0	1160	-65	- 6	59	16,430	21.4	4.1	25.5
	5.7	1100	-63	35	98	25,900	23.3	4.2	47.0
	5.4	1175	-63	-13	50	14,000	21.5	3.9	55.0

[1]Satisfactory combustion, not a limit.

[2]Combustion would cease with a small reduction in combustion-air flow, hence a combustion limit.

FOR SMALL COMBUSTION-AIR FLOWS

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	Combustion air		Fuel						
Nominal pressure altitude (ft)	Inlet temperature (°F)	Pressure drop $\sigma_1 \Delta P$ (in. water)	Flow (lb/hr)	Temperature (°F)	Heating value (Btu/hr)	Heater efficiency (percent)	Fuel-air ratio	Exhaust-gas temperature (°F)	Remarks
Sea level	-34	0.6	1.45	-14	29,000	64.0	0.0984	70	(1)
	-36	.6	.96	-11	19,100	85.3	.0654	90	
	-37	.6	.71	- 9	14,200	91.6	.0477	92	
	-37	.9	.58	- 9	11,600	94.8	.0400	85	
	-38	.7	.47	-10	9,400	91.5	.0324	75	
10,000	-22	0.3	1.20	-22	24,000	67.3	0.1000	50	(1)
	-35	1.2	.76	-14	15,200	104.2	.0644	45	
	-36	1.5	.54	-23	10,900	118.5	.0474	40	
	-10	1.1	.44	-21	8,800	117.6	.0375	52	
	- 5	2.2	.35	-20	7,000	96.3	.0297	50	
20,000	2	--------	1.00	1	20,000	44.9	0.1075	50	(2)
	-35	0.1	.71	0	14,200	40.5	.0654	35	
	-34	.2	.55	-10	11,000	87.6	.0504	70	
	-34	.3	.47	- 7	9,400	128.7	.0456	75	
	-35	--------	.36	-12	7,300	143.0	.0317	83	
25,000	-36	--------	0.85	-10	17,000	61.0	0.0988	70	(2)
	-35	--------	.59	- 6	11,800	81.6	.0694	68	
	-34	--------	.46	- 2	9,100	54.6	.0495	53	
	-33	--------	.38	6	7,600	52.2	.0388	50	
	-30	--------	.33	14	6,600	67.7	.0373	50	
30,000	-32	--------	0.91	- 1	18,200	61.8	0.0900	70	(2)
	-28	0.7	.66	-11	13,200	70.0	.0600	70	
	-28	.2	.50	- 3	10,000	84.3	.0459	90	
	-28	--------	.38	2	7,600	104.2	.0354	92	
	-28	.5	.29	2	5,800	128.0	.0266	75	
35,000	-30	0.4	1.77	-19	35,400	32.2	0.1010	140	(2)
	-29	.7	1.21	-16	21,400	25.4	.0700	75	
	-30	.2	.88	-14	17,600	35.5	.0512	57	
	-30	.2	.69	-13	13,800	43.4	.0396	52	
	-30	.4	.57	-13	11,400	50.7	.0330	43	
40,000	-24	0.3	1.71	-18	34,200	34.7	0.1024	182	(2)
	-23	.4	1.12	-11	22,400	50.1	.0667	157	
	-20	.4	1.00	- 6	20,000	27.3	.0562	85	
	-23	.2	.82	-18	15,180	71.8	.0400	213	
	-48	.9	1.18	-26	21,820	112.3	.0294	500	
45,000	-41	0.2	2.00	-25	37,000	41.1	0.1096	233	(2)
	-39	.2	1.32	-15	26,400	19.2	.0726	110	
	-30	.4	1.38	-18	25,530	64.3	.0541	280	
	-34	1.5	2.00	- 7	37,000	70.0	.0426	495	
	-39	1.7	2.00	- 9	37,000	38.0	.0364	250	

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TABLE IV - HEATER PERFORMANCE FOR LARGE COMBUSTION-AIR FLOWS

Run	Pressure altitude (ft)	Inlet pressure (in. Hg abs.)	Ventilating air						Combustion air	
			Flow (lb/hr)	Inlet temperature (°F)	Outlet temperature (°F)	Temperature rise (°F)	Enthalpy change (Btu/hr)	Pressure drop (in. water)	Inlet pressure (in. Hg abs.)	Downstream pressure (in. Hg abs.)
162	10,000	20.6	1125	-66	234	300	81,000	7.4	20.4	18.5
(2)	39,000	5.5	1100	-65	---	---	---	---	9.2	4.9
(2)	38,000	5.8	1100	-65	---	---	---	---	10.3	5.8
(2)	37,500	6.0	1100	-65	---	---	---	---	11.9	6.0
(2)	37,000	6.1	1100	-65	---	---	---	---	12.5	6.1
(2)	37,000	6.1	1100	-65	---	---	---	---	13.2	6.1
(2)	36,500	6.3	1100	-65	---	---	---	---	13.9	6.3
(2)	36,000	6.5	1100	-65	---	---	---	---	14.9	6.5
165	36,000	6.5	1100	-66	20	86	22,700	18.4	17.2	7.0
166	39,000	5.6	1080	-65	-9	56	14,500	19.4	19.4	5.0

Run	Combustion air			Fuel			Heater efficiency (percent)	Fuel-air ratio	Exhaust-gas temperature (°F)	Remarks
	Flow (lb/hr)	Inlet temperature (°F)	Pressure drop (in. water)	Flow (lb/hr)	Temperature (°F)	Heating value (Btu/hr)				
162	177	-47	26.1	11.30	-23	209,000	38.75	0.064	1805	(1), (4)
(2)	180	---	59.0	6.00	---	---	---	.033	---	(4)
(2)	200	---	61.1	6.66	---	---	---	.033	---	(4)
(2)	240	---	80.2	8.00	---	---	---	.033	---	(4)
(2)	260	---	87.0	8.66	---	---	---	.033	---	(4)
(2)	280	---	96.5	9.33	---	---	---	.033	---	(4)
(2)	300	---	103.3	10.00	---	---	---	.033	---	(4)
(2)	320	---	114.2	10.70	---	---	---	.033	---	(4)
165	388	-62	138.7	13.05	-38	241,600	9.00	.034	434	(3)
166	514	-62	196.0	13.44	-29	249,000	5.80	.026	215	(5)

[1]Further increase in combustion-air flow for this fuel-air ratio was not attempted because of excessive exhaust-gas temperatures.

[2]Trial runs.

[3]The combustion-air flow and pressure drop considered to be above the range of practical interest.

[4]Satisfactory combustion, not a limit.

[5]Combustion would cease with a small increase in combustion-air flow, hence a combustion limit.

TABLE V - HEATER

[Voltage across the

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Nominal pressure altitude (ft)	Inlet pressure (in.Hg abs.)	Combustion-air flow (lb/hr)	Combustion-air inlet temperature (°F)	Fuel flow (lb/hr)	Fuel temperature (°F)	Fuel-air ratio	Starting time (min)			Ventilating air-entrance temperature (°F)
							First start	Second start	Third start	
Sea level	29.9	35	-42	3.50	-56	0.100	0.55	2.05	1.92	-60
		35	-42	2.33	-56	.066	1.00	.95	1.43	-60
		35	-42	1.75	-56	.050	.20	.77	1.80	-60
		40	-54	4.00	-55	.100	1.80	1.70	(a)	-70
		50	-41	5.00	-50	.100	.65	.50	.83	-65
		50	-41	3.33	-50	.066	1.50	1.50	(b)	-65
		60	-48	6.00	-60	.100	.22	.62	.38	-76
		60	-48	4.00	-60	.066	.38	.55	.42	-76
		60	-48	3.00	-60	.050	.68	1.86	.51	-76
		60	-48	2.00	-60	.033	(a)	(a)	(b)	-76
		70	-53	3.50	-56	.050	.49	.90	.35	-71
		70	-53	2.33	-56	.033	(a)	(a)	(b)	-71
		90	-54	3.00	-55	.033	.81	.92	.97	-70
		160	-66	16.00	-54	.100	.21	.88	.28	-81
		240	-69	16.00	-56	.066	.48	.46	.96	-80
		240	-69	12.00	-56	.050	.75	.80	.95	-80
		240	-69	8.00	-56	.033	.70	.42	.31	-80
		260	-63	17.33	-51	.066	1.10	.54	.62	-74
		260	-63	8.67	-51	.033	1.14	.83	.81	-74
		280	-71	14.00	-61	.050	1.14	.60	.55	-80
		280	-71	9.33	-61	.033	1.15	1.13	1.00	-80
10,000	20.6	35	-47	3.50	-56	0.100	0.33	0.29	0.96	-65
		35	-47	2.34	-56	.066	.44	.54	.28	-65
		35	-53	1.75	-63	.050	.60	.86	.60	-77
		35	-53	1.17	-63	.033	(a)	2.00	.50	-77
		40	-47	4.00	-56	.100	.30	.27	.24	-65
		40	-47	2.67	-56	.066	.33	.68	.95	-65
		40	-62	2.00	-69	.050	.55	.58	.90	-82
		40	-52	1.33	-47	.033	.60	.69	.95	-77
		60	-60	3.00	-70	.050	.61	.55	.46	-84
		60	-60	2.00	-70	.033	.61	1.62	.75	-84
		100	-53	10.00	-50	.100	.22	.25	.22	-70
		100	-53	6.67	-50	.066	.22	.21	.23	-70
		100	-53	5.00	-50	.050	.22	.22	.23	-70
		100	-50	3.33	-40	.033	.26	.20	.25	-72
		120	-57	12.00	-44	.100	.22	.22	.22	-73
		120	-51	8.00	-45	.066	.20	.16	.15	-74
		120	-51	4.00	-45	.033	.42	.43	1.66	-74
		130	-68	13.00	-61	.100	.88	1.00	.85	-82
		140	-62	14.00	-61	.100	1.65	(a)	(a)	-75
		140	-55	9.33	-48	.066	1.00	.27	.26	-74
		140	-55	4.67	-48	.033	1.30	.83	.80	-74
		150	-62	10.00	-61	.066	1.00	.86	.25	-75
		150	-62	7.50	-61	.050	1.00	.96	.91	-75
		150	-62	5.00	-61	.033	1.00	.94	.96	-75
		160	-62	16.00	-44	.100	(a)	(a)	(a)	-75
		160	-62	10.67	-44	.066	2.12	1.43	1.15	-75
		160	-62	8.00	-44	.050	1.05	.99	1.00	-75
		160	-62	5.33	-44	.033	.95	.70	1.38	-75
		170	-57	8.50	-44	.050	1.22	1.17	1.30	-73
		170	-57	5.67	-44	.033	1.53	1.53	1.09	-73
20,000	13.5	15	-29	1.50	-31	0.100	0.99	1.45	1.35	-67

[a] No ignition.

[b] No attempt at ignition.

IGNITION CHARACTERISTICS
ignitor was held at 28.5 volts]

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Nominal pressure altitude (ft)	Inlet pressure (in. Hg abs.)	Combustion-air flow (lb/hr)	Combustion-air inlet temperature (°F)	Fuel flow (lb/hr)	Fuel temperature (°F)	Fuel-air ratio	Starting time (min)			Ventilating-air-entrance temperature (°F)
							First start	Second start	Third start	
20,000	13.5	15	-35	1.00	-32	0.066	(a)	1.70	0.60	-72
		15	-35	0.75	-32	.050	(a)	(a)	0.80	-72
		20	-29	2.00	-31	.100	0.55	0.51	1.05	-67
		20	-29	1.33	-31	.066	.73	.89	.50	-67
		20	-29	1.00	-31	.050	.47	.35	.35	-67
		25	-52	2.50	-52	.100	.50	.29	.33	-72
		25	-52	1.67	-52	.066	.74	.38	.71	-72
		25	-52	1.25	-52	.050	.89	.58	1.00	-72
		25	-52	.83	-52	.033	(a)	(a)	.63	-72
		30	-52	3.00	-52	.100	.48	.97	.50	-72
		30	-52	2.00	-52	.066	.41	.47	.41	-72
		30	-52	1.50	-52	.050	.50	.38	.54	-72
		30	-52	1.00	-52	.033	.86	.57	.54	-72
		40	-47	4.00	-54	.100	.36	.34	.90	-70
		40	-47	2.67	-54	.066	.51	.91	.54	-70
		40	-47	2.00	-54	.050	.50	.49	.30	-70
		40	-42	1.33	-53	.033	.42	.32	.45	-67
		50	-52	5.00	-48	.100	.31	.31	.37	-70
		50	-52	3.33	-48	.066	.80	.59	.56	-70
		50	-50	2.50	-52	.050	.31	.51	.48	-70
		50	-52	1.67	-48	.033	.30	.55	.45	-70
		60	-49	6.00	-40	.100	.38	.40	.25	-68
		60	-49	4.00	-40	.066	.40	.50	.25	-68
		60	-49	3.00	-51	.050	.90	.60	.50	-68
		60	-49	2.00	-51	.033	.52	(a)	.32	-68
		70	-47	7.00	-54	.100	.87	.30	.38	-70
		70	-47	4.67	-54	.066	.48	.40	.38	-70
		70	-47	3.50	-54	.050	.73	(a)	(a)	-70
		70	-47	2.33	-54	.033	(a)	(a)	(a)	-70
		80	-54	8.00	-52	.100	1.35	.42	1.45	-80
		80	-54	5.33	-52	.066	1.35	1.45	1.17	-80
25,000	10.8	20	-29	2.00	-31	0.100	(a)	1.35	1.30	-67
		20	-29	1.33	-31	.066	1.20	1.35	1.18	-67
		25	-42	2.50	-52	.100	.53	.48	.39	-69
		25	-42	1.67	-52	.066	.60	.52	.51	-69
		25	-42	1.25	-52	.050	.60	(a)	(a)	-69
		25	-42	.83	-52	.033	(a)	(a)	.90	-69
		30	-36	3.00	-44	.100	.65	.97	1.25	-69
		30	-36	2.00	-44	.066	.81	.62	1.00	-69
		30	-36	1.50	-44	.050	.61	.62	1.06	-69
		30	-36	1.00	-44	.033	(a)	.82	.53	-69
		40	-38	4.00	-40	.100	.93	.80	.82	-70
		40	-38	2.66	-40	.066	.57	1.07	1.03	-70
		40	-38	2.00	-40	.050	.60	(a)	(a)	-70
		40	-37	1.33	-45	.033	.60	(a)	.95	-69
		50	-30	5.00	-28	.100	.65	(a)	.71	-65
		50	-38	3.33	-40	.066	(a)	.99	(a)	-70
		50	-38	2.50	-40	.050	(b)	(b)	(b)	-70
		50	-37	1.66	-45	.033	(a)	(a)	(a)	-69
30,000	8.8	30	-38	3.00	-44	0.100	0.41	1.14	1.16	-74
		30	-38	2.00	-44	.066	1.44	1.25	1.67	-74
		40	-35	4.00	-28	.100	(a)	(a)	.91	-64

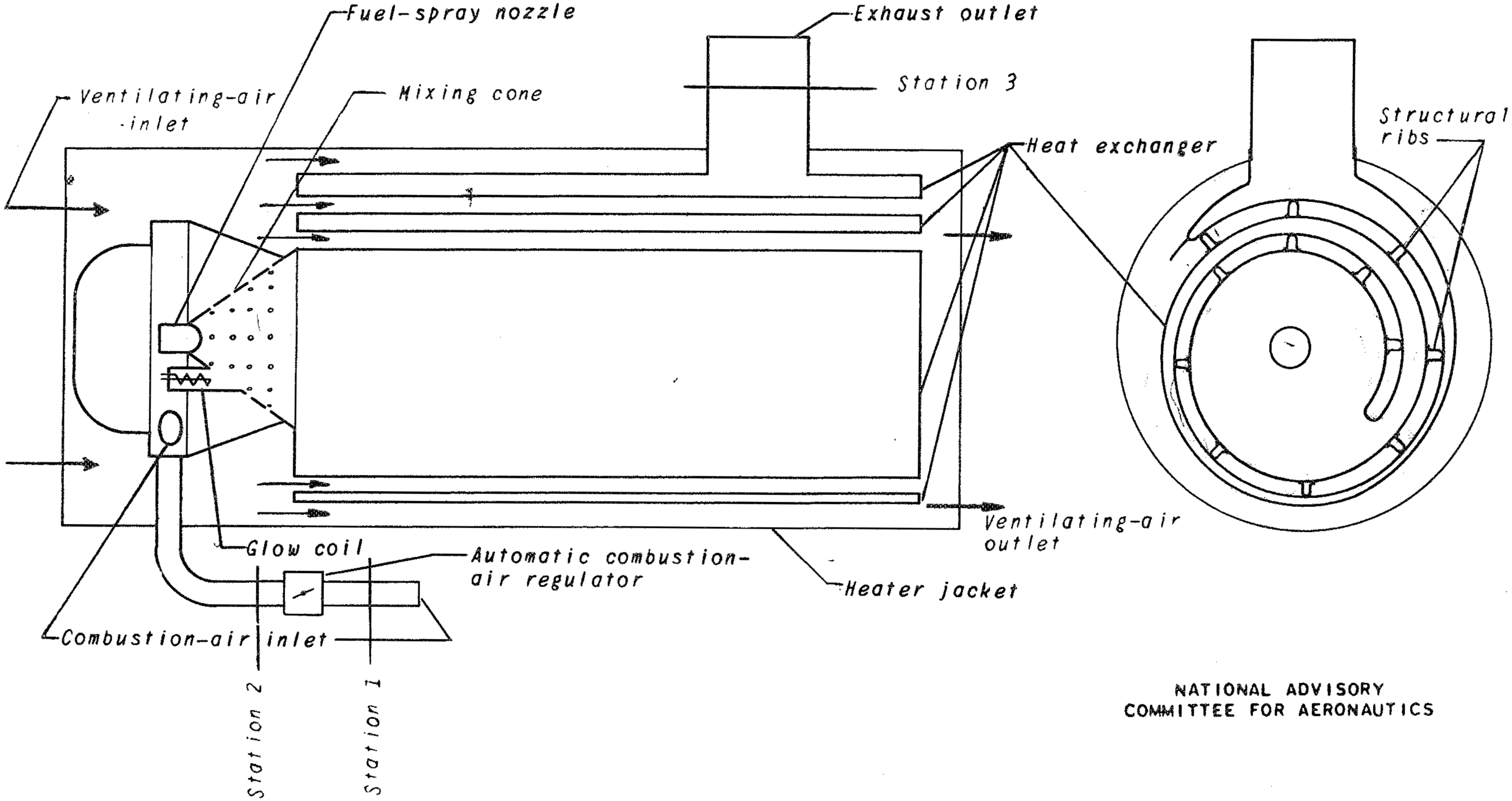

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Figure 1. - Diagram of Stewart-Warner model 906-B combustion heater.

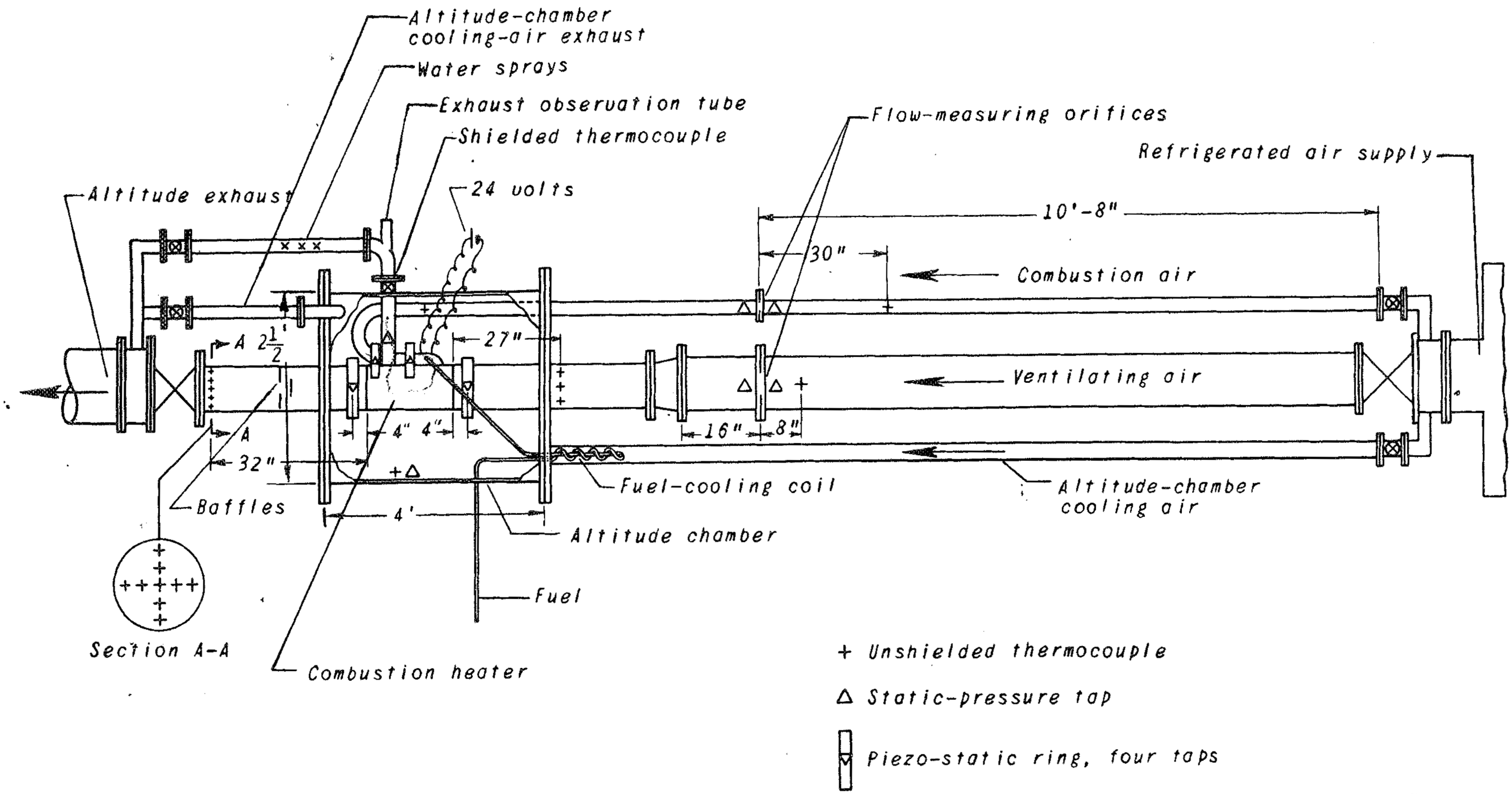

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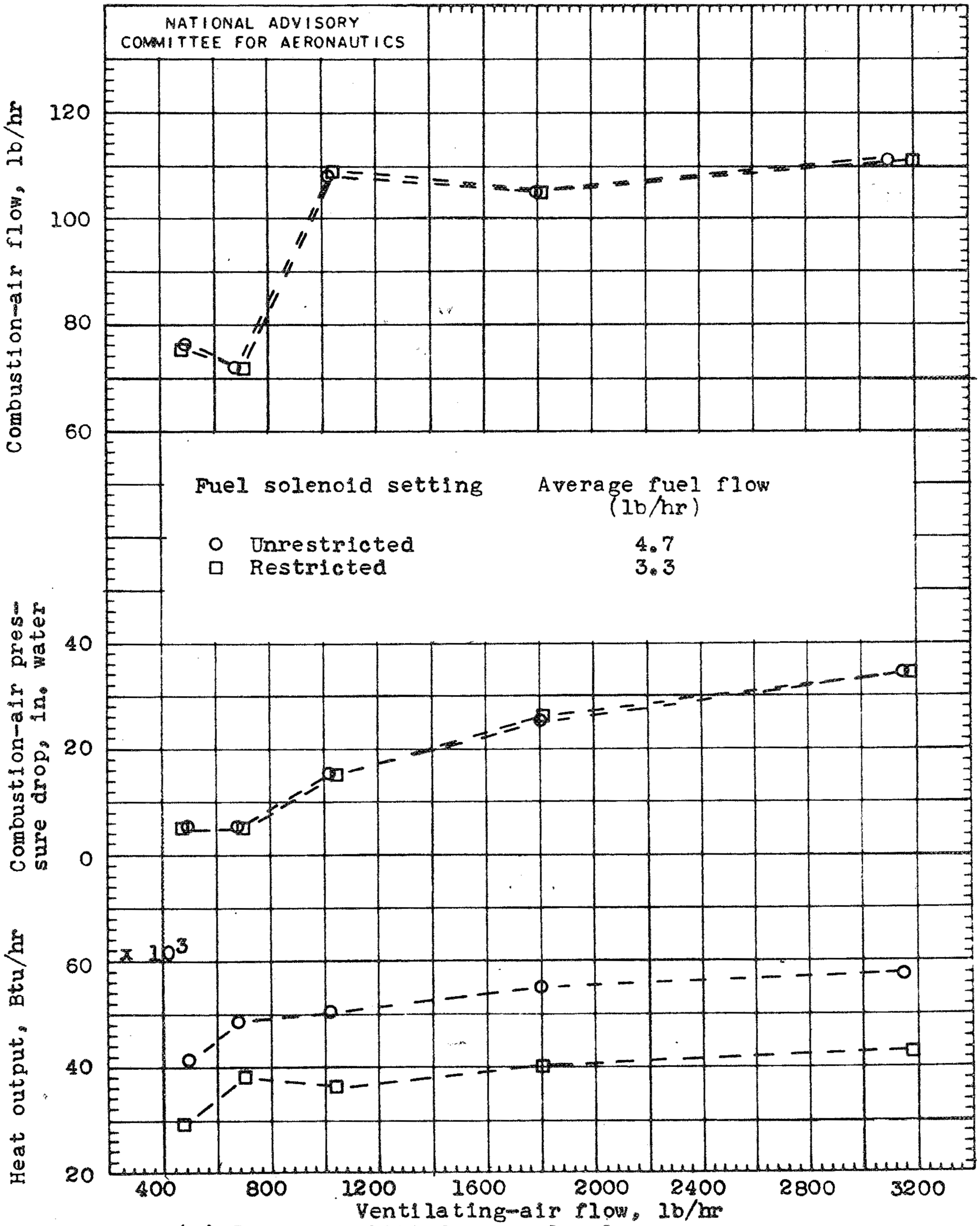
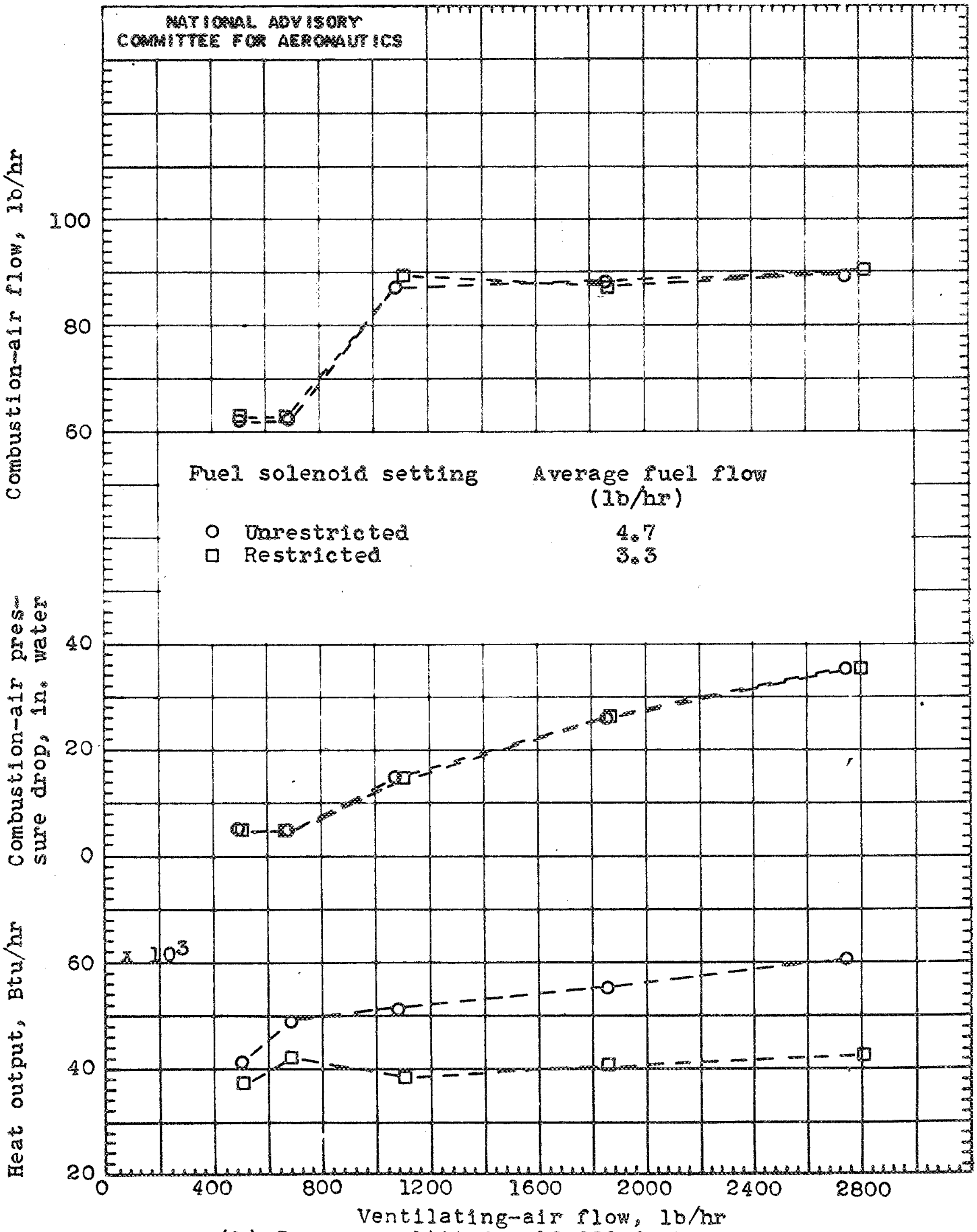
Figure 2. - Schematic diagram of test setup for combustion heater.



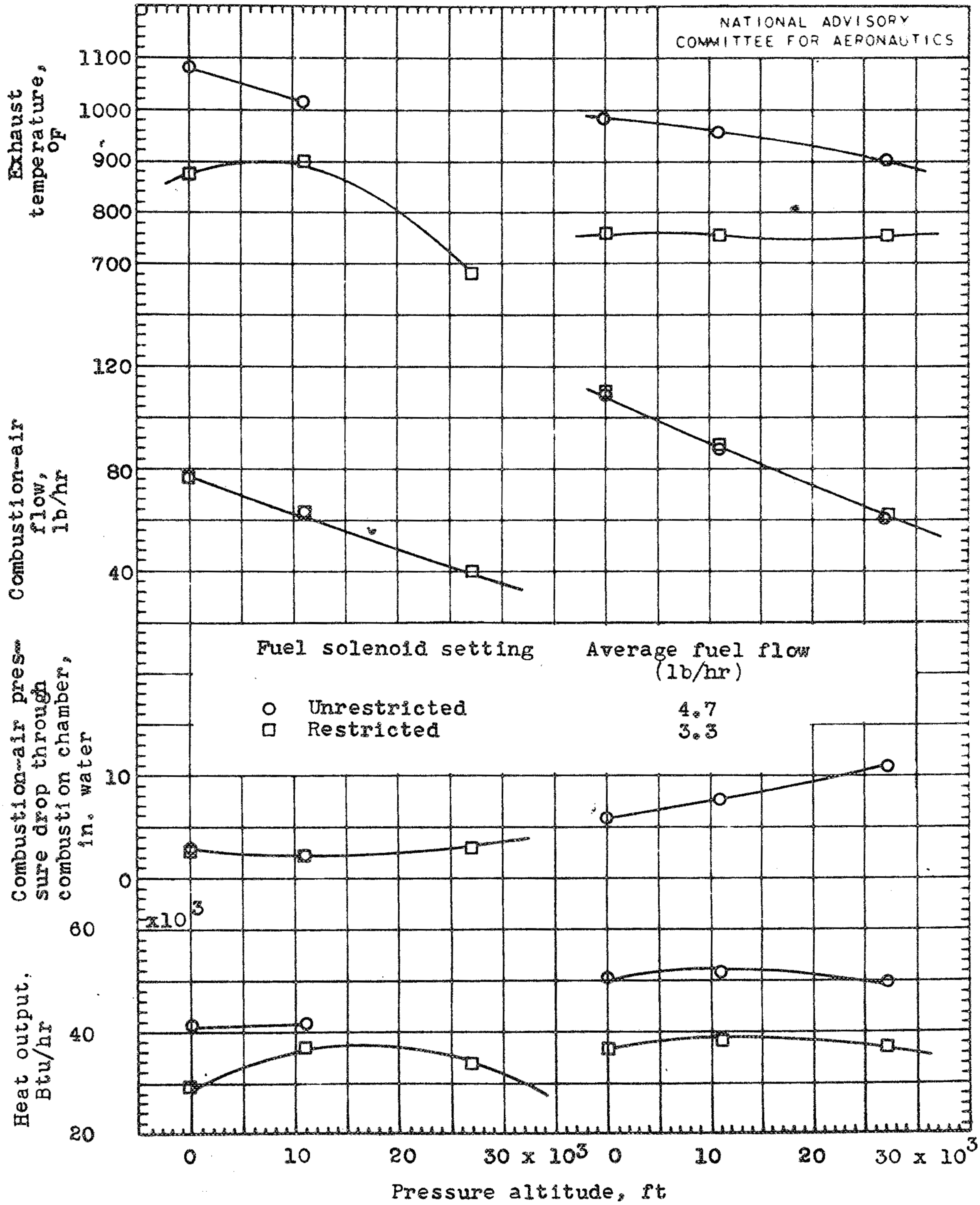
(a) Pressure altitude, sea level.

Figure 3. - Heater performance with automatic controls installed. Ventilating-air inlet temperature, 59° F; approximate combustion-air inlet temperature, 75° F.



(b) Pressure altitude, 10,000 feet.

Figure 3. - Concluded. Heater performance with automatic controls installed. Ventilating-air inlet temperature, 59° F; approximate combustion-air inlet temperature, 75° F.



(a) Nominal ventilating-air flow, 500 pounds per hour; nominal combustion-air pressure drop, 5.0 inches water.

(b) Nominal ventilating-air flow, 1100 pounds per hour; nominal combustion-air pressure drop, 15.0 inches water.

Figure 4. - Effect of pressure altitude on heater performance with automatic controls installed. Ventilating-air inlet temperature, 59° F; approximate combustion-air inlet temperature, 75° F.

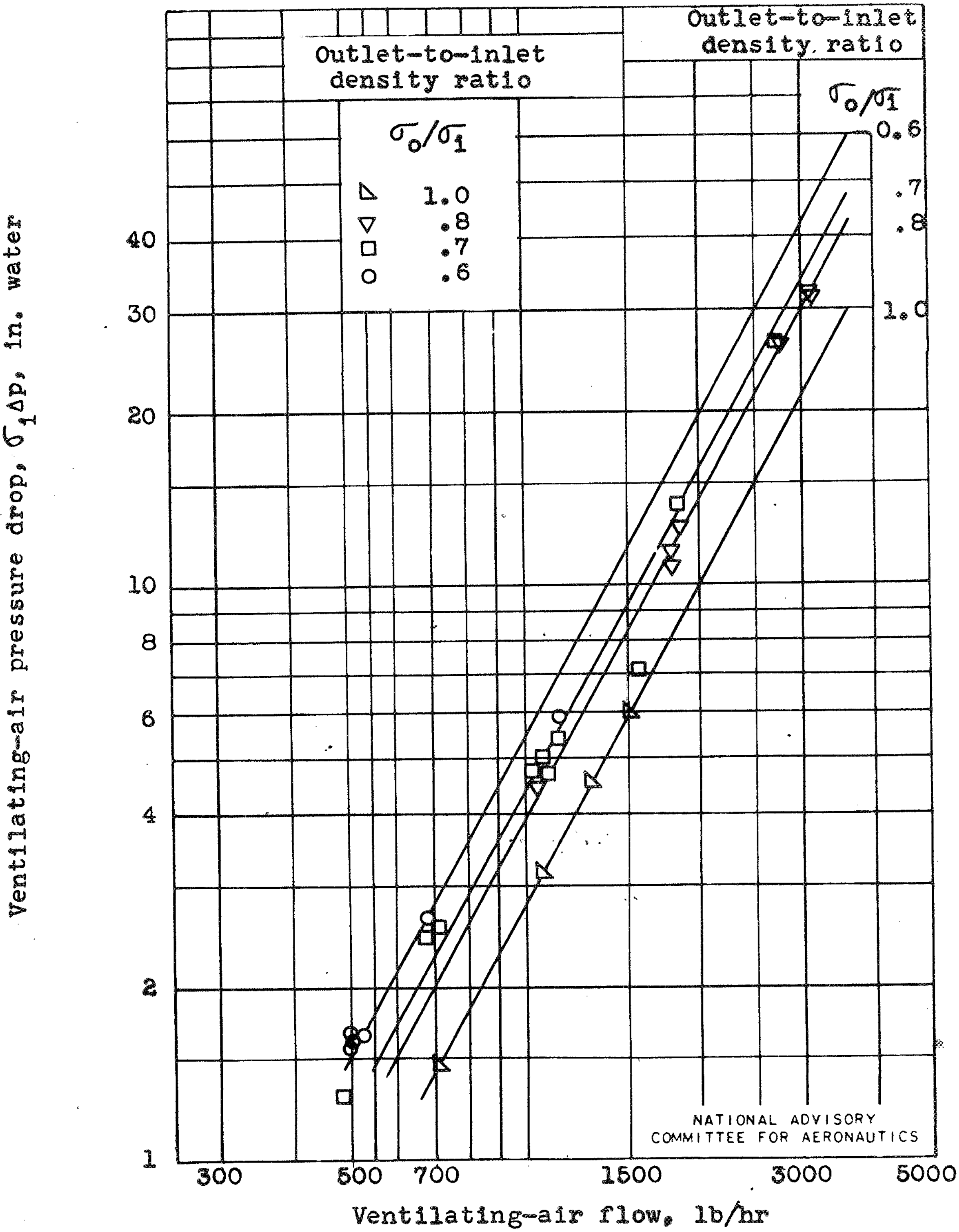


Figure 5. - Ventilating-air pressure drop.

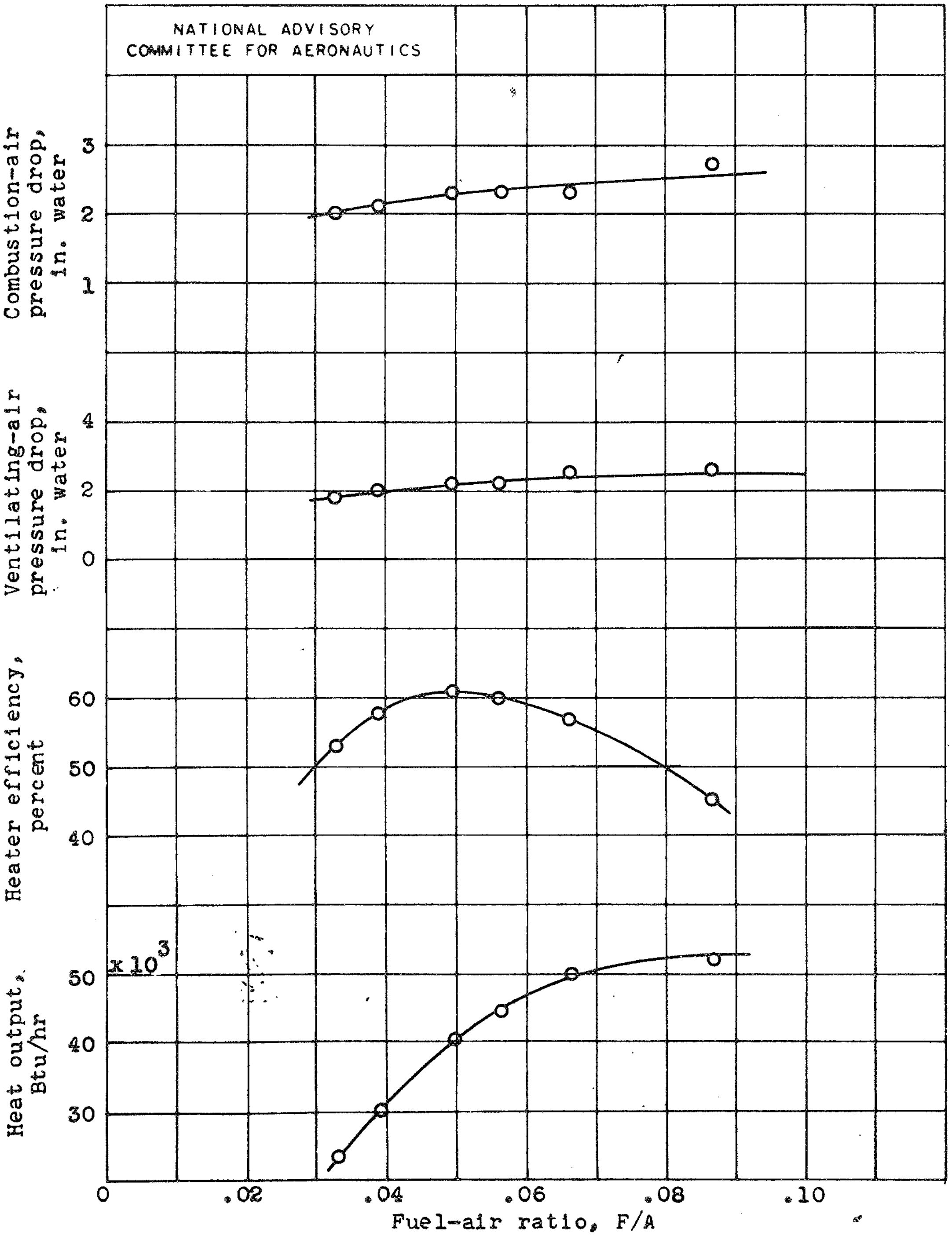


Figure 6. - Effect of fuel-air ratio on heater efficiency. Ventilating-air inlet temperature, 0° F; combustion-air inlet temperature, 14° F; sea-level pressure altitude; ventilating-air flow, 690 pounds per hour; combustion-air flow, 72.7 pounds per hour.

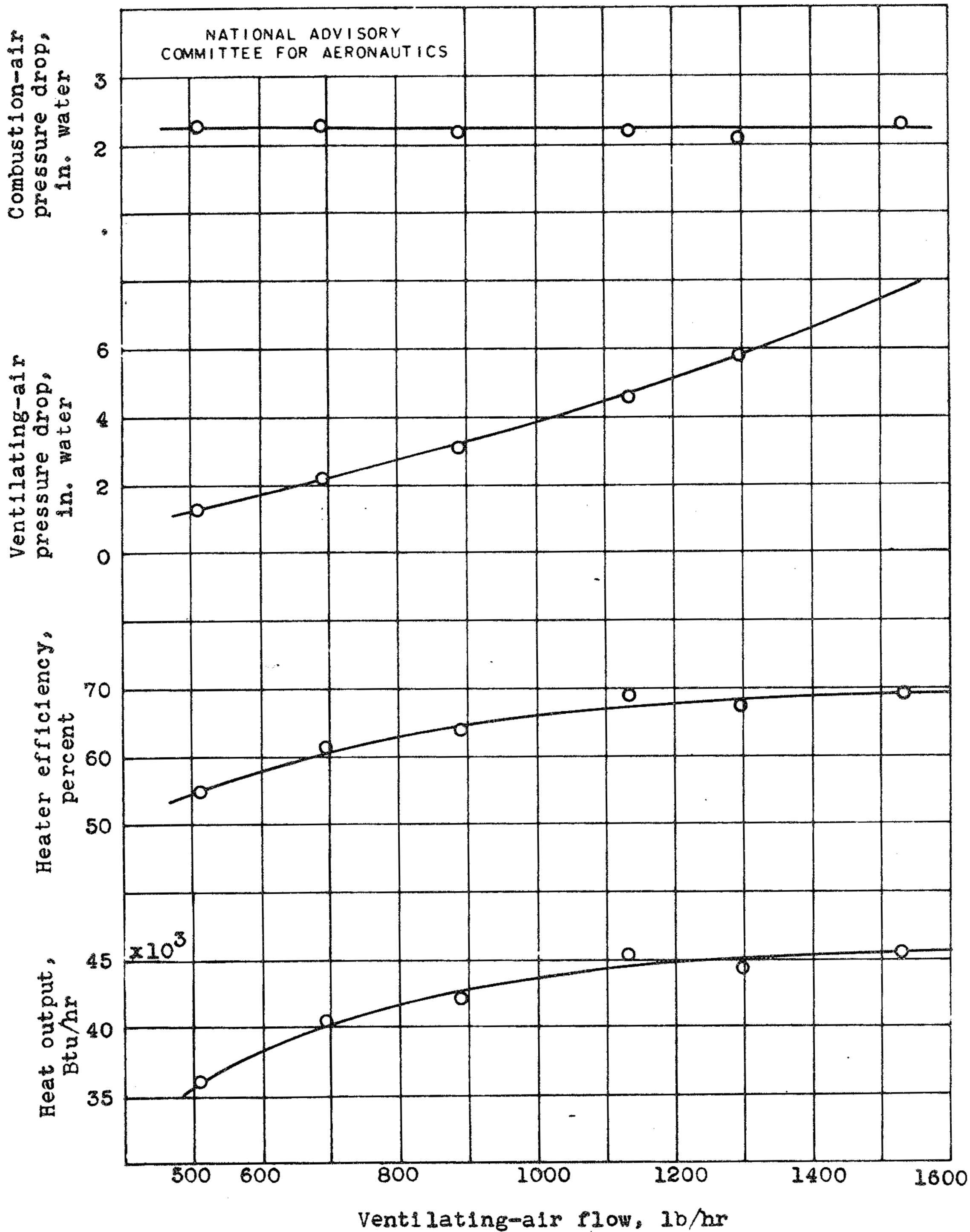
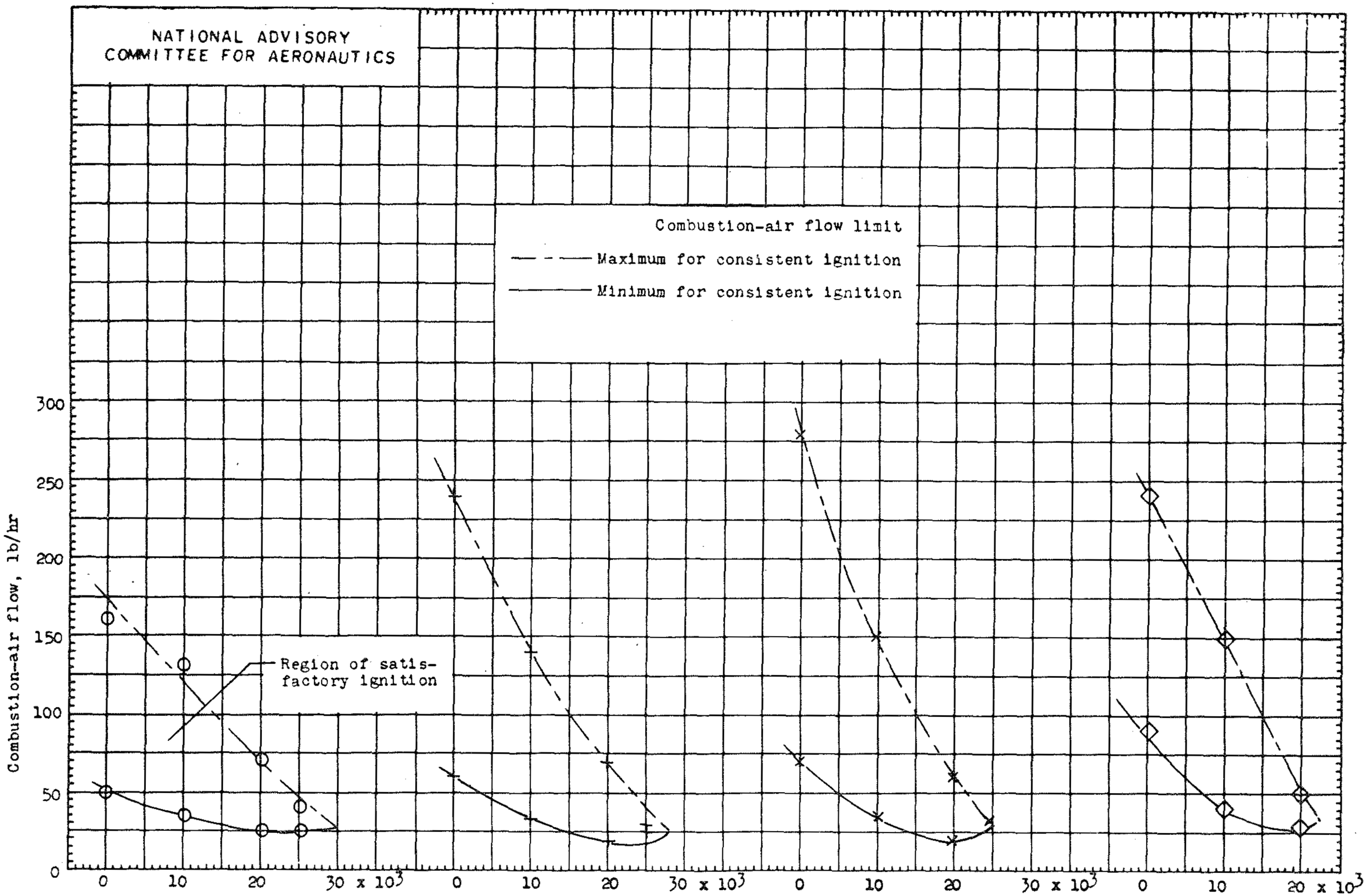


Figure 7. - Heat output at fuel-air ratio for maximum efficiency, 0.05. Ventilating-air inlet temperature, 0° F; combustion-air inlet temperature, 14° F; sea-level pressure altitude; combustion-air flow, 72.7 pounds per hour; fuel flow, 3.6 pounds per hour.



(a) Fuel-air ratio, 0.10. (b) Fuel-air ratio, 0.066. (c) Fuel-air ratio, 0.05. (d) Fuel-air ratio, 0.036.

Figure 8. - Combustion-air-flow limits for consistent ignition. Ventilating-air inlet temperature, approximately -65° F; combustion-air temperature, -29° to -71° F; maximum ignition time, 1 minute for each of three attempts.